PCT / IB 98 / 01920

29. 12. 98

The Patent Office

The Patent Office
Cardiff Road
Newport
Gwent
NP9 1RH

IB98/01920

REC'D 05 JAN 1999
WIPO PCT

5

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation and Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed

Dated 30 NOV 1998

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Patents Form 1/77

Patents Act 1977
(Rule 16)

The Patent Office

28NOV97 E320722-2 D01874
P01/7700 25.00 - 9725126.8

Request for grant of a patent

(See notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

THE PATENT OFFICE
G
27 NOV 1997
RECEIVED BY HAND

The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

1. Your reference

CG/SAR/97126GB

2. Patent application number
(The Patent Office will fill in this part)

9725126.8 27 NOV 1997

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

Catharina Svanborg
66 St Johns Wood High Street
London NN8 7SH

Patents ADP number *(if you know it)*

7328552001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

THERAPEUTIC AGENTS

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

BATCHELLOR, KIRK & CO.,

2 PEAR TREE COURT,
FARRINGDON ROAD,
LONDON EC1R ODS.

Patents ADP number *(if you know it)*

315001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*

a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
See note (d))

NO

Patents Form 1/77

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	27
Claim(s)	0
Abstract	0
Drawing(s)	9 x 2

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	x ADDITIONAL APPLICANT SHEET

11. I/We request the grant of a patent on the basis of this application.

Signature Batchellor/Kirk & Co. Date

Batchellor, Kirk & Co. 27/11/97

12. Name and daytime telephone number of person to contact in the United Kingdom

CAROL GREAVES - 01934 844419

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.

b) Write your answers in capital letters using black ink or you may type them.

c) If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.

d) If you have answered 'Yes' Patents Form 7/77 will need to be filed.

e) Once you have filled in the form you must remember to sign and date it.

f) For details of the fee and ways to pay please contact the Patent Office.

CONTINUATION SHEET FOR PATENTS FORM NO. 1/77

Full name, address and postcode of the or each applicant:

Per Anders Håkansson

Flormans gatan 2A
s-223 54 Lund
Sweden

7332653001

Therapeutic Agents

The present invention relates to agents which are useful in the diagnosis and treatment of malignancies such as cancer therapy, to processes for their production and to pharmaceutical compositions containing them.

Apoptotic cell death is characterised by loss of cytoplasmic material, nuclear changes with marginalisation of chromatin and by the formation of apoptotic bodies (L.M. Schwartz et al., Immunol. Today 1993, 14:582-590, D.J. McConkey et al. Mol. Aspects Med. (1996) 17:1-115, J.F.Kerr et al., Cancer (1994) 73:2013-26). The reduction in cell viability is accompanied by DNA fragmentation that proceeds in steps with initial formation of high molecular weight (HMW) DNA fragments (50-300kbp) and the subsequent appearance of oligonucleosome length DNA fragments consisting of oligomers of approximately 200bp. (M.J. Arends et al., Am. J. Pathol. (1990) 136: 593-608, B. Zhivotovosky et al., FEBS Lett. (1994) 352;150-4). Cytoplasmic proteases and Ca^{2+}-dependant signaling pathways are activated prior to DNA fragmentation, and are regarded as a prerequisite for the nuclear changes (B. Zhivotovsky et al. Exp. Cell Res. (1995) 221:404-412m S.Kumar et al., TIBS, (1995) 20:198-202). Agonists like Fas-ligand and TNF first bind to cell surface receptors and then activate transmembrane signaling events that cause cytoplasmic and nuclear changes (L.G. Zheng et al., Nature (1995) 377: 348-351, W.P. Declercq et al, Cytokine (1995, 7:701-9, T.S. Griffith, Science, (1995) 270:1189-1192). Endonuclease activation and DNA fragmentation require that signals from the cytoplasm reach the nucleus. The mechanisms of nuclear uptake and signaling across the nuclear membrane in apoptotic cells remain poorly understood.

The transport of macro-molecules from the cytoplasm into the nucleus is highly regulated. Nuclear pore complexes (NPCs) are

the sites of exchange of macromolecules between cytoplasm and nucleoplasm (D.A. Jans et al., Physiol. Rev (1996) 76: 651-685, D. Gorlich et al., Science (1996) 271:1513-1518, and Y. Yoneda, J. Biochem. (1997) 121:811-817). The NPCs allow passive diffusion of molecules smaller than 30 kDa but larger proteins like ovalbumin are delayed and bovine serum albumin (66kDa) does not enter the nucleoplasm. Entry of large molecules or complexes into the nucleus requires active transport and is commonly carrier mediated. The specificity for the carrier may be determined by the so called nuclear targetting or nuclear localization sequences (NLS) that characterize proteins with the ability to enter the nucleus. For example, binding of glucocorticoids to their receptor releases HSP 90 that binds to unoccupied receptors and reveals a NLS in the glucocorticoid receptor sequence that leads to the transport of the glucocorticoid ligand-receptor complex into the nucleus (J. Yang et al., Mol. Cell. Biol. (1994) 14: 5088-98 issn 0270-7306).

A protein complex obtainable from milk that induces apoptosis in tumour cells and immature cells but spares other cells has been described previously (Proc. Natl. Acad. Sci, USA, 92, p8064-8068). The active complex was initially isolated from human casein by ion-exchange chromatography and was shown by N-terminal amino acid sequencing and mass spectrometry to contain a multimeric form of α-lactalbumin (MAL). Monomeric α-lactalbumin is the major protein component in human milk whey, where it occurs at concentrations around 2mg/ml (W.E. Heine et al., J. Nutr. (1991) 121: 277-83), but monomeric α-lactalbumin isolated from human whey did not induce apoptosis. It is possible that the mechanism by which the multimer induces apopotosis may relate to the Ca^{2+} binding properties of MAL since apoptosis required extracellular calcium.

MAL may be derived from other sources of α-lactalbumin such as bovine, sheep or goats milk or human whey.

It has now been found that MAL is taken up by susceptable cells (i.e. tumour cells) and accumulated in cell nuclei. This high uptake by the nucleus, combined with its multimeric protein structure, means that MAL would provide a useful carrier for other moieties for example, cytotoxins or chemotherapeutic agents whose effect would supplement the effect of MAL in killing tumour cells, or diagnostic reagents such as dyes or radio- or other labels which would allow identification of tumour cells, whilst at the same time, allowing MAL to exert a killing effect on those cells.

The present invention provides a reagent comprising a protein complex comprising a multimeric form of α-lactalbumin (MAL) and a further reagent which is combined with MAL such that it is carried into the nucleoplasm of cells which are susceptible to MAL.

The said further reagent may be coupled by conjugation or by covalent bonding for example by way of a linking or spacer group as would be understood in the art. Enzymatic reactions can mediate or facilitate the coupling.

Recombinant production techniques allows also the possiblity that MAL could be produced in the form of a fusion protein with the said further reagent.

Examples of said further reagents include cytoxins such as known chemotherapeutic reagents used for the treatment of cancer, microbial toxins such as diptheria toxin and monoclonal antibodies. Alternatively, the said further reagent comprises a labelling agent such as biotin or radioactive labels such as ^{125}I. For example, a labelling group can be introduced into a protein using an enzymatic reaction or by having a labelled building stone (such as radioactive isotopes e.g. ^{14}C, ^{35}S,) within the protein. ^{125}I-labelling can be performed enzymatically by coupling ^{125}I to the protein with the help of lactoperoxidase. Biotinylation of the protein is performed by letteing D-biotinoyl-ε-aminocaproic acid-N-

hydroxysuccinimide ester react with the protein by forming a stable amide bond to free amino groups in the protein.

Protein may also be labelled by adding radioactive amino acid during the production of a recombinantly produced protein.

Depending upon the nature of the said further reagent, the complex of the invention can be used in the diagnosis and/or treatment of cancer. For this purpose, the complex is suitably formulated as a pharmaceutical composition and these form a further aspect of the invention.

The complex can be administered in the form of an oral mucosal dosage unit, an injectable composition, or a topical composition. In any case the protein is normally administered together with the commonly known carriers, fillers and/or expedients, which are pharmaceutically acceptable.

In case the protein is administered in the form of a solution or cream for topical use the solution contains an emulsifying agent for the protein complex together with a diluent or cream base. Such formulations can be applied directly to the tumour, or can be inhaled in the form of a mist into the upper respiratory airways.

In oral use the protein is normally administered together with a carrier, which may be a solid, semi-solid or liquid diluent or a capsule. Usually the amount of active compound is between 0.1 to 99% by weight of the preparation, preferably between 0.5 to 20% by weight in preparations for injection and between 2 and 50% by weight in preparations for oral administration.

In pharmaceutical preparations containing complex in the form of dosage units for oral administration the compound may be mixed with a solid, pulverulent carrier, as e.g. with lactose, saccharose, sorbitol, mannitol, starch, such as potato starch, corn starch, amylopectin, cellulose derivatives or gelatine, as well as with an antifriction agent, such as magnesium

stearate, calcium stearate, polyethylene glycol waxes or the like, and be pressed into tablets. Multiple-unit-dosage granules can be prepared as well. Tablets and granules of the above cores can be coated with concentrated solutions of sugar, etc. The cores can also be coated with polymers which change the dissolution rate in the gastrointestinal tract, such as anionic polymers having a pk_a of above 5.5. Such polymers are hydroxypropylmethyl cellulose phthalate, cellulose acetate phthalate, and polymers sold under the trade mark Eudragit S100 and L100.

In preparation of gelatine capsules these can be soft or hard. In the former case the active compound is mixed with oil, and the latter case the multiple-unit-dosage granules are filled therein.

Liquid preparations for oral administration can be present in the form of syrups or suspensions, e.g., solutions containing from about 0.2% by weight to about 20% by weight of the active compound disclosed, and glycerol and propylene glycol. If desired, such preparations can contain colouring agents, flavouring agents, saccharine, and carboxymethyl cellulose as a thickening agent.

The daily dose of the active compound varies and is dependant on the type of administrative route, but as a general rule it is 1 to 100 mg/dose of active compound at personal administration, and 2 to 200 mg/dose in topical administration. The number of applications per 24 hours depend of the administration route, but may vary, e.g. in the case of a topical application in the nose from 3 to 8 times per 24 hours, i.e., depending on the flow of phlegm produced by the body treated in therapeutic use.

The invention further provides a method for treating cancer which comprises administering to cancer cells a complex or a composition as described above.

Diagnostic applications of the complex of the invention may be carried out *in vivo* or *in vitro* for example on biopsy samples. For this purpose, a complex comprising a label may be applied to the suspect tumour in the form of a pharmaceutical composition when used *in vivo* or any formulation when used *in vitro*. The tumour can then be observed in order to determine whether the complex penetrates into the nucleus or not. Visibility of the nucleus would be indicative that the complex has been absorbed into the nucleus and is a MAL susceptible tumour. Although the degree of uptake of MAL is variable, it is taken up by cancer cells generally and therefore may be used in killing those cells, particularly when combined with another cellular toxin in a complex of the invention. Uptake of MAL is particularly high in lymphoid tumour cells such as leukaemia cells. Even in carcinoma cells such as lung cancer cells, there is sufficient uptake to result in cell death as will be illustrated hereinafter. The information obtained using diagnostic methods of the invention may assist in determining a future treatment regime.

The interaction of MAL with different cellular components was studied by confocal microscopy, using biotinylated MAL, and by subcellular factionation using ^{125}I-labelled MAL. Monomeric α-lactalbumin and human IgG were used as controls.

MAL was found to accumulate in cell nuclei rather than the cytosol, the vesicular fraction or the ER-Golgi complex. The nuclear accumulation of MAL occurred rapidly in cells that were susceptible to its apoptosis-inducing effects, but not in resistant cells. Nuclear uptake was through the nuclear pore complex and was critical for the induction of apoptosis, since inhibition of nuclear uptake with WGA rescued digitonin-permeabilized cells from apoptosis. Ca^{2+} was required for MAL induced DNA fragmentation but nuclear uptake of MAL was independent of Ca^{2+}.

The results demonstrated that MAL can target cell nuclei and that nuclear targeting mechanisms are more readily available

in cells that are sensitive to MAL-induced apoptosis than in resistant cells. It appears that apoptosis induction occurs at least in part through a direct effect of MAL at the nuclear level.

Cell surface binding of MAL as a possible decisive step in apoptosis induction was investigated first. Exogenous apoptosis-inducing molecules like Fas-ligand or TNF bind to their respective cell surface receptors and trigger transmembrane signalling event and intracellular pathways leading to apoptosis. MAL bound quickly to cell surfaces, was saturate at high MAL concentrations and was specific as defined by competition experiments where labelled MAL was competed out by unlabeled MAL. By confocal microscopy MAL was shown to bind in patches, suggested that either MAL bound as preformed aggregates, or that the bound MAL accumulated in certain areas of the membrane through capping or other mechanisms influencing receptor distribution. There was little quantitative difference in cell surface binding of monomeric, inactive and multimeric, active forms of the protein. Furthermore, there was no difference in cell surface binding to sensitive and resistant cells. The results suggested that MAL differs from agonists like TNF and Fas-ligand in that cell surface binding does not itself trigger apoptosis. Recently Sheridan et al.(Science, (1997) 277:818-821 and Pan et al. (Science (19970 277:815-818) described a decoy receptor lacking the signalling domain of the native receptor, in the membrane of healthy cells [Pan, 1997 #640, ; Sheridan, 1997 #639]. The TRAIL protein binds cell surface receptors with similar affinity, but will not be able to induce an apoptosis-signal in healthy cells.

MAL was rapidly taken into the nuclei of cells that were sensitive to its apoptosis inducing effect, suggesting that it was capable of nuclear targeting. This term is used herein to describe preferential localisation of certain molecules to the nuclear compartment. Molecules of diverse origin, structure and function share the ability to reach cell nuclei, and may exert their main functions there as opposed to the

cytoplasmic compartment. The uptake of MAL into the nucleus was via the nuclear pore complex as shown by inhibition studies using WGA, a lectin that binds to glycosylated regions of the nucleoporins and sterically hinders transport of the importin-protein complex through the nuclear pore (S.A. Adam et al., (1990) J. Cell Biol. 111:807-816). WGA treatment blocked MAL uptake into the nuclei of digitonin-treated cells and inhibited the MAL-induced DNA fragmentation. The structural basis for and mechanism of nuclear uptake of MAL need to be identified. Classical nuclear targeting sequences often include clusters of basic amino acids, that share little or no sequence homology (Jans et al. (1996) supra., J. Garcia-Bustos et al., Biochim Biophys. Acta. (1991) 1071: 83-101). Sequence analysis of the monomeric form of α-lactalbumin did not show the presence of known nuclear targeting motifs and the monomer did not target cell nuclei. It is likely, therefore that MAL carried structural modifications that confer affinity for the nuclear compartment, the nuclear membrane and/or the nuclear pore.

The susceptibility to MAL-induced apoptosis in difference cells was proportional to the nuclear accumulation of MAL. MAL rapidly entered the nuclei of the sensitive L1210 cells. At a concentration of 0.3mg/ml nuclear staining was observed after 1 hour in 10% of cells and increased to 75% after 6 hours. DNA fragmentation was first seen after 6 hours incubation . Nuclear uptake occurred more slowly in the intermediary sensitive A549 cell line and was low or absent in human kidney cells.

The difference was not observed when the total, cell-associated MAL or cytoplasmic uptake of MAL was compared between the cells. Uptake into the cytoplasm occurred with similar kinetics in the L1210, A549 and HRTEC cells. The total amount of intracellular MAL was highest in the L1210 cells but most of this was in the nuclei and not in the cytoplasm. This suggested that the nuclear uptake was the decisive step. Further evidence for a direct effect of MAL at the nuclear level was obtained using isolated nuclei. MAL

constituents present in MAL are required for nuclear targeting and induction of apoptosis.

Human milk provides the breast-fed infant with a mucosal immune system. Molecules in milk prevent microbial attachment to mucosal tissues, lyse viral particles, disrupt bacterial cell walls and prevent microbial growth (H. McKenzie et al., Adv. Protein Chem., (1994) 44: 173-313, J.J Kabara et al., Antimicrob. Agents Chemother (1972) 2:23-28, F.D. Gillin et al., Science (1983) 221: 1290-1292). Epidemiological studies consistently find lower frequencies of viral and bacterial infections in breast-fed infants. Epidemiological studies have also provided compelling evidence that breast-feeding may protect against cancer. Breast-fed individuals have a lower incidence of lymphomas and other malignancies, and the frequency decreases with the length of breast-feeding (M.K. Davis et al., Lancet (1988) ii: 365-368). There are other reports to suggest that the breast cancer incidence is reduced in women who breast-feed their children (V. Siskind et al., Am. J. Epidemiol. (1989) 130: 229-236, P.A. Newcomb et al., N. Engl. J. Med. (1994) 330: 81-87) Our studies provide a potential mechanism for the reduced disease frequencies. MAL may reach the rapidly proliferating cells in the gut of the breast-fed infant and drive selection through maturity and away from the neoplasia or reach the mucosa-associated lymphoid tissue and influence the function of local lymphocyte populations.

The invention will now be particularly described by way of example with reference to the accompanying diagrammatic drawings in which:

Figure 1A shows the results of viability studies on the incubation of three cell types with different concentrations of MAL incubated for different lengths of time. The viability was determined by trypan blue exclusion as % of cells exposed to medium alone;

permeablized cells were incubated with biotinylated protein for 20 minutes, washed, counterstained with FITC-conjugated strepavidin and visualised by confocal microscopy. Nuclear DNA was counterstained with 25µg/ml of propidium iodide. Nuclear staining is shown for cells exposed to streptavidin alone (a) IgG (b) ALA (c and d) and MAL (e and f). For inhibition experiments the digitonin-permeabilized cells were preincubated with 50µg/ml of WGA before the addition of biotinylated protein. Nuclear uptake of MAL was inhibited with WGA (f), but ALA was still taken up (d); and

Figure 7 illustrates the uptake of ^{125}I-labeled MAL, ALA and IgG into different intracellular compartments. L1210, A549 and HRTEC cells were exposed to 10^6 cpm of radiolabeled protein for 6hours, 24 and 24 hours.

In the examples, the following reagents were used:

FITC conjugated swine anti-rabbit antibodies, and FITC conjugated streptavidin were from Dakopatts a /s (Glostrup, Denmark). DEAE-Trisacryl M was from BioSepra (Villeneuve la Garenne, France). The Biotin Labelling kit was from Boeringer Manheimer GmbH (Germany) and ^{125}I was from Amersham (UK). Flowcheck™ and Flowser™ fluorospheres were from Coulter Inc. (Hialeah, FL, USA). Seaplaque GTG Low melting temperature agarose gel and SeaKem GTG agarose were from SeaKem, FMK Bioproducts (Rockdale, USA). Dulbecco's modified Eagle's medium, Hank's balanced salt solution (HBSS), RPMI 1640, fetal calf serum (FCS), L-glutamine, 2-mercaptoethanol, penicillin, streptomycin, gentamicin and 1 kD DNA ladder was from Gibco/BRL, Life Technology Ltd (Paisley Scotland, UK). Boric acid, dimethylsulfoxide, Na_2HPO_4, NaCl, KH_2PO_4, $MgCl_2$, NaAzid, Tween-20 and tris(hydroxymethyl) aminomethane was from Kebo Lab (Stockholm, Sweden). The PD-10 column, heparin and percoll solutions were from Pharmacia Biotech (Stockholm, Sweden), α-lactalbumin, leupeptin, antipain, PMSF, Triton X-100, NP-40, CHAPS, trypsin, butyrate, N-lauroylsarcosine, sodium periodate, proteinase K, tunicamycin, lactoperoxidase, EDTA,

EGTA, collagenase type I, DNAse type IV and two sets of pulse markers: chromosomes from *Saccharomyces cerevisiae* (225-2200 kbp) and a mixture of λDNA Hind III fragments, λDNA and λDNA concatemers (0.1-200kbp) were from Sigma Chemicals Inc (St Louis, USA).

The murine lymphoblastoid leukemia cell line L1210 (ATCC CLL 219) was cultured in in RPMI 1640 supplemented with 10% FCS, 2 mM glutamine and 50µg of gentamicin per ml with the addition of 50 µM 2-mercaptoethanol. Cells were aspirated from the flasks, harvested by centrifugation, washed and resuspended in RPMI.

The human lung carcinoma cell line A549 (ATCC CLL 185) was cultured as described above but without 2-mercaptoethanol in the medium. The cells were detached by versene (0.2 g Sodium EDTA per liter PBS) for about 10 min at 37°C. Detached cells were harvested by centrifugation at 320 x *g* for 10 min and resuspended in RPMI.

Human renal tubular epithelial cells (HRTEC) were isolated from the kidney of a three year old boy whose kidney was removed due to hydronephrosis and reduced function. Renal cotex was dissected from renal medulla, minced and collected by centrifugation at 250 x *g* for 10 min. The cortical fragments were incubated overnight at 4°C on a rotational platform in phosphate buffered saline (PBS) 0.15M pH7.2 containing 0.1% collagenase type I (Sigma) and 0.04% DNAse type IV (Sigma). Tissue was collected by centrifugation (250 x *g* for 10 min) and diluted in an equal volume HBSS, supplemented with 15% fetal calf serum. The tissue was resuspended in eight volumes of HBSS with 15% FCS, applied to the top of a two step Percoll gradient: 30 and 50% diluted in HBSS, centrifuged at 1500 x *g* for 20 min at 4°C and the interface collected. This interface was diluted in four volumes of HBSS with 15% FCS, centrifuged at 250 x *g* for 10 min and resuspended in Primaria flasks in Dulbecco's modified Eagle's medium supplemented with 15% FCS, 2 mM L-glutamine, 20

and 250µ of ice-cold lysis buffer (0.5% Triton X-100, 5 mM Tris, 20mM EDTA, pH 8.0), vortexed and allowed to lyse on ice for 1 h. DNA fragments were separated from intact chromatin by centrifugation at 13,000 x *g* for 15 min. The supernatant was transferred to new tubes and DNA was precipitated at -20°C after addition of 1ml cold, absolute ethanol and 25µl of 5M NaCl. Precipitated DNA was pelleted by centrifugation at 13,000 x *g* for 15 min and dried in a Speed-Vac Concentrator (Savant Instruments Inc., Farmingdale, NY, USA) until ethanol had vaporised. The pellet was resuspended in 30µl of TE-buffer and incubated for 1h at 37°C with 1mg/ml of RNAse A followed by 1h with 500µg/ml of Proteinase K. Samples were loaded on 1.8% agarose gels, and run overnight applying a 40 V constant voltage. DNA was visualised under ultraviolet light (305 nm) after straining with ethidium bromide (6 µg/ml) and photographed using Polaroid 55 positive-negative film. DNA size was calibrated using 1 kD DNA ladder (Gibco BRL, Life Technologies LTD., Paisley, UK), consisting of 1018 bp dsDNA fragment repeats and vector DNA ranging from 75-1636 bp.

High molecular weight DNA fragments were detected by field-inversion gel electrophoresis (FIGE). Briefly, cells (2 x 10^6) were suspended in 180 µl of buffer (0.15 M NaClaniacal, 2 mM KH_2PO_4/KOH, pH 6.8, 1 mM EGTA, 5mM $MgCl_2$) and 180 µl of 37°C molten 1% low melting point agarose gel (SeaKem, FMK Bioproducts, Rockdale, USA) and pipetted into plugs at precoled plates and left for 10 min at 4°C. The plugs were incubated in 1ml/plug of incubation buffer (10 mM NaCl, 10 mM Tris, pH 9.5, 25 mM EDTA, 1% N-lauroylsarcosine, supplemented with proteinase K at a final concentration of 0.2 mg/ml) at 50°C for 24 h. The incubation was followed by rinsing in 3 changes of TE-buffer at 4°C for 2h. The plugs were stored in 50mM EDTA until run. Electrophoresis were run at 180V in 1% agarose gels in 0.5 x TBE (45 mM Tris, 1.25mM EDTA, 45 mM boric acid, pH 8.0), at 12°C, with the ramping rate changing from 0.8s to 30s for 24h, using a forward to reverse ratio of 3:1. DNA size calibration was performed using two sets of pulse markers: chromosomes from *Saccharomyces cerevisiae* (225-

2200 kbp) and a mixture of λDNA and λDNA concatemers (0.1-200kbp) purchased from Sigma. Gel staining and photography were performed as described above.

The L1210 cells died when exposed to 0.5 mg/ml of MAL, with 50% of the cells remaining viable after 6 h. The A549 cells required a higher concentration (1.25 mg/ml of MAL) and a longer incubation time (24 hours) in order for 50% of the cells to loose their viability. The HRTEC cells remained fully viable after 24 h incubation with up to 4 mg/ml of MAL. Monomeric α-lactalbumin had no effect on cell viability even at 10mg/ml.

The kinetics of DNA fragmentation are shown in fig. 1B. DNA fragmentation was highly time and concentration dependant. HMW DNA fragments were observed in the L1210 cells after 30 min incubation with MAL (0.5 mg/ml) and oligonucleosome length DNA fragments were detected after three hours. At lower MAL concentrations (0.3mg/ml) fragmentation of DNA was first seen after 6 h and at higher concentrations of MAL (0.75mg/ml) fragmentation was seen already at 2 h. At later times no fragmentation was seen due to secondary lysis of cells.

In the A549 cells HMW fragmentation was first detected after 6 h incubation with 1.0mg/ml and was maximal at 1.5 mg/ml. Further breakdown of DNA was observed with higher concentrations of MAL until finally no chromosomal DNA was seen (2.5 mg/ml).

The HRTEC cells did not undergo HMW DNA fragmentation after exposure to 4 mg/ml of MAL for 24 h.

These results demonstrated that differential sensitivity to MAL-induced apoptosis among the cell types studied. The L1210 cell line was highly sensitive, the A549 cells were intermediately sensitive and the non-transferred cultures were resistant to the effects of the protein complex within the

tested concentration range. The monomeric form of the protein was inactive.

Example 2

Cell surface binding of MAL complexes

MAL, human α-lactalbumin (HLA) and immunoglobulin G were biotinylated according to the manufacturer's instructions or labelled with ^{125}I with the lactoperoxidase method. Proteins were dissolved in PBSA-T buffer (30 mM Na_2HPO_4, 120mM NaCl, pH 7.4, with 0.1% NaAzid, 0.05% Tween-20) and 25 µl of protein (25 µg) was incubated with 2µl of ^{125} (0.2Ci), 2 µl of lactoperoxidase (2.5mg/ml) and 2 µl of H_2O_2 (diluted 1:2000 in PBS) for 2 min at room temperature. The reaction was stopped by the addition of 500 µl of PBSA-T. The labelled protein was purified on a PD-10 column. 500 µl fractions in PBSA-T were eluted and fractions containing radioactivity were stored at -20°C. The labelled protein eluted in 1 ml of buffer and had an activity of approximately 2 x 10^8 cpm.

L1210, A549 and HRTEC cells (3 x 10^6 cells/ml, 50µl) were incubated in suspension with 50µl of biotinylated MAL, ALA or BSA for various times at 37°C. The cells were washed with PBS by centrifugation at 320 x *g* for 10 min and the supernatant was discarded. FITC-conjugated streptavidin (diluted 1:50 in PBS) was added and the cells were incubated for 30 min at room temperature. The cells were washed by centrifugation as above, suspended in 300 µl PBS and the surface fluorescence was analysed by flow cytometry on a Coulter Epics Profile II flow-cytometer (Coulter Inc.), equipped with a 488 nm argon laser. Green fluorescence was detected with a 525nm band pass filter. The PMT voltage was initially set to1250 V and adjusted for day to day variation using calibration with Immunobeads (Coulter).

Cell surface bound material was examined by confocal microscopy, and quantitated by flow cytometry. Binding to the

three cell types was detected after 10 min and reached a maximum after 30 min incubation, with a fluorescence intensity measured by flow cytometry that was 12.1, 13.4 and 8.5 times that of the streptavidin control. MAL was distributed in patches separated by unstained areas (fig. 2A) seen on confocal microscopy.

Cell surface binding of MAL was also quantitated as the cell associated radioactivity during the first 30 min after addition of ^{125}I-labelled MAL to the cells. Surface binding of radiolabelled protein to L1210, A549 or HRTEC cells in suspension (3 x 10^6 cells/ml, 100 µl) was quantitated in an Epics γ-counter (Coulter Inc.) after incubation with 1 x 10^6 cpm of ^{125}I-labelled MAL, ALA or IgG for 30 min at 37°C and the cells were washed three times by centrifugation at 320 x g for 10 min with PBS.

Binding increased with the concentration of MAL, reaching saturation at 23 000, 20 000 and 18 000 cpm for L1210, A549 and HRTEC cells, respectively, after 30 min of exposure to 2 x 10^6 cpm compared to 1500 and 1300cpm for L1210, and A549 cells of IgG. There was no difference in cell surface binding of MAL between the three cell types (fig. 2B). Employing this method the binding of -125^I labelled ALA was lower than that of MAL. After 30 minutes of exposure to 2 x 10^6cpm of ALA binding was 5 000, 7 000 and 7 500 cpm for the L1210, A549 and HRTEC cells, respectively.

Example 3

Nuclear uptake of MAL

To detect intracellular protein, the cells were fixed at various times after addition of 0.3 mg/ml of biotinylated MAL for 5 min in phosphate-buffered paraformaldehyde (4%) (B. Sander et al., Immunol. Rev. (1991) 119: 65-92) at room temperature, washed in PBS, and permeabilized with 0.1% saponin in PBS. FITC conjugated streptavidin (diluted 1:100 in 0.1% saponin) was added and the cells were incubated for 30

min at room temperature. The cells were washed twice in PBS-saponin and once in PBS, mounted on a glass slide and analysed in a Bio-Rad 1024 laser scanning confocal equipment (Bio Rad Laboratories, Hemel-Hempstead, UK) attached to a Nikon Diaphot inverted microscope.

Permeabilization with the saponin allowed entry of streptavidin. Cells treated with medium, biotinylated BSA or α-lactalbumin served as controls (fig.3). Nuclear uptake of MAL was shown to occur rapidly in cells that were sensitive to its apoptosis-inducing effects. Nuclear staining of L1210 cells was first detected after about 2 hours in about 10% of the cells, and after 6 hours more than 70% of L1210 cell nuclei stained brightly. Cytoplasmic staining was not observed in those cells. Nuclear localisation of MAL in the A549 cells required longer incubation times. About 15% of A549 cell nuclei stained brightly. In the meantime, MAL was observed in the cytoplasm of A549 cells as granular fluorescence evenly distributed throughout the cell. Nuclear uptake was not observed in the HRTEC cells exposed to the biotinylated MAL (1mg/ml, fig 3). There was a marked differencein the nuclear uptake of ALA compared to MAL. Nuclear staining of ALA was only detected in circa. 30% of L1210 cells after 6 hours and in about 15% OF A549 cells after 24 hours. No staining of ALA was detected in the HRTEC cells.

Example 4

Radiolabelled Studies of Intracellular distribution.

The intracellular distribution of MAL was further analysed in cells exposed to ^{125}I-labelled MAL with ^{125}I-labelled α-lactalbumin and IgG as controls (fig 4). Subcellular fractions were prepared after mechanic disruption of the cells and the amount of radiolabelled MAL in each fraction was determined in relation to the total cell-associated radioactivity measured prior to disruption of the cells. Fraction P1 contained the cell nuclei, P2 contained the plasma membranes and mitochondria, P3 contained mostly ER and Golgi membranes and

small vesicles. Fraction S contained the cytosolic proteins. The purity of the fractions was determined by quantitation of specific markers (DNA, alkaline phosphatase, RNA and catalase).

Specifically, cellular subfractionation was performed as described (J. Graham., Isolation of subcellular organelles and membranes., p161-1019. in D. Rickwood ed., Centrifugation, a practical approach, 2nd ed. IRL Press, Washington DC). L1210, A549 or HRTEC cells in suspension (3 x 10^6 cells/ml, 100 µl10 were incubated with 1 x 10^6 cpm of ^{125}I-labelled MAL, ALA or IgG for various times at 37°C. The cells were washed three times with ice-cold PBS and the supernatants were discarded. The cells were suspended in 500 µl of homogenisation buffer (10 mM Tris-HCl, pH 7.8, 5 mM $MgCl_2$ and 2 mM $CaCl_2$ for L1210 cells and 0.15M NaCl, 2 mM EDTA, pH 7.5 for A549 cells), and homogenised by 50 strokes in a Dounce homogenizer (Thomas, Philadelphia, USA) with pestle size 415. Sucrose was added to a final concentration of 250 mm and the homogenate was centrifuged at 100 x *g* for 25 min at RT. The first pellet contained nuclei, large mitochondria and large sheets of plasma membrane. The remaining supernatant was further centrifuged at 12 000 x *g* for 30 min at 4°C resulting in a second pellet containing mitochondria, plasma membrane and cytoplasmic organelles. The supernatant was finally centrifuged at 150 000 x *g* for 2 h at 4°C resulting in a pellet containing small vesicles, endoplasmic reticulum and a supernatant containing cytosolic proteins.

Specific cellular compartments were detected using enzymatic or chemical assays as described (Graham. supra. P.309-333).

DNA and RNA were detected in the fractions by the binding of ethidium bromide. Sample (1 vol) was mixed with 1 vol of heparin solution (25 µg/ml) and 1 ml of PBS or with 1 vol of heparin, 1 vol of RNAse A (50 µg/ml) and 1 vol of PBS. The samples were incubated at 37°C for 20 min and 1 vol of ethidium bromide was added (25 µg/ml). Fluorescence was measured after

60 s incubation using an excitation wavelength of 360 nm and an emission wavelength of 580 nm. PBS served as blank, 1 vol of homogenate in 4 vol of PBS served as background correction factor and the fluorescence was compared to a DNA standard (25 µg/nl of λDNA).

Catalase activity was measured by mixing sample (0.5 ml) with H_2O_2 (0.5 ml), for 3 min at 4°C. H_2SO_4 (0.1 ml) was added to stop the reaction, $KMnO_4$ (0.7 ml) was added and the optical density of the sample was measured at 480nm within 1 min.

Alkaline phophatase activity was detected by mixing 50 µl of sample with 200 µl of assay mixture (5 ml of 16mM *p*-nitrophenylphosphate solution, 5 ml of 50 mM sodium borate buffer (pH 9.5) and 20 µl of 1 M $MgCl_2$) and incubated at 37°C for 60 min. The absorbance was measured at 410nm.

The distribution of ^{125}I-labelled MAL and kinetics of uptake in the different cellular compartments, are shown in fig.4. As with biotinylated MAL there were differences in nuclear localisation of ^{125}I-labelled MAL between the cell types. MAL accumulated in nuclei of L1210 cells with about 78% of the total radioactivity (34200/44000) recovered from the nuclear fraction (P1) after 6 h. MAL uptake into the nuclei of HRTEC cells was slow was slow with only 16% (2200/14000) of the total cell associated radioactivity in the nuclear fraction after 24 h of incubation. The A549 cells formed an intermediary group with about 52% of ^{125}I-labelled MAL in the nuclear fraction (13700/27000) after 24 h. The total amount of cell-associated MAL in the other subcellular fractions did not differ to the same degree between the cell types. At the final time-point of measurement 4500cpm (10%), 5100 cpm (195) and 2100 cpm (15%) were found in the pellet 2 from the L1210, A549 and HRTEC cells , respectively, and 800 cpm (2%), 1400 cpm (5%) and 1100 cpm (8%) were found in pellet 3 and 4500 cpm (10%), 6800 cpm (25%) and 8600 cpm (61%0 were found in the cytosolic fractions.

Active nuclear uptake was performed according to Adams et al. ((1990) supra.), with some modifications.

Briefly, 1 x 10^6 cells were incubated in 100 µl of nuclear transport buffer (NTB), with the addition of 1 µg/ml each of leupeptin, aprotinin, antipain, and 40 µg/ml of digitonin for 5 min at room temperature and washed by centrifugation at 320 x *g* for 10 min in NTB. Biotinylated protein (5 µl, 5mg/ml) was added to the cells in a total volume of 100 µl NTB supplemented with phosphcreatin, creatine phosphokinase and ATP, incubated for various time at RT and washed twice in NTB by centrifugation at 320 x *g* for 10 min. The cells were treated with 0.2% Triton-X100 in NTB for 6 min and washed finally 1:100 dilution of fluorescein-conjugated strepatvidin was added for 30 min at RT and washed. The cells were then inspected by fluorescence microscopy in a Nikon Microphot (Japan) microscope or by laser scanning confocal microscopy in a BioRad MRC-1024 instrument.

A low degree of spontaneous DNA fragmentation occurred in unstimulated nuclei from the three cell types but MAL enhanced the formation of HMW DNA fragments after one hour and oligonucleosome length fragments after 2 hours.

Digitonin permeabilizes the plasma membrane, but leaves the nuclear membrane intact. L1210, A549 and HRTEC cells were permeabilized with digitonin in nuclear transport buffer, washed and exposed to biotinylated MAL in buffer supplemented with phosphocreatin, creatin phosphokinase and ATP. Human IgG and monomeric α-lactalbumin were used as controls. MAL was taken directly into the nuclei of digitonin treated cells with maximum levels reached after 20 min (Fig 6).

When adding 0.4 mg/ml of MAL to digitonin-permeabilized cells, HMW DNA fragments were formed after 1 hour and oligonucleosomal fragments after 2 hours. IgG was not detected in isolated nuclei or in nuclei of digitonin-permeabilized cells (Fig 5). ALA entered nuclei of digitonin-

permabilzed cells as predicted by its molecular mass (14kDa) and produced bright staining of the nuclei. IgG was not detected in isolated nuclei or in nuclei of digitonin-permabilized cells (Fig. 6).

These experiments demonstrated that both ALA and MAL was transported into the nuclei, but that only MAL could induce DNA fragmentation in isolated nuclei, apparently in the absence of activated cytoplasm. There was however, no difference in sensitivity to MAL-induced DNA fragmentation between nuclei from the three cell types. This suggested that the differential sensitivity to MAL was determined by the nuclear targeting process rather than by the effect on the nuclei *per se*.

Example 6

Role of the nuclear pore complex for the nuclear uptake of MAL.

The role of active transport over the nuclear pore was examined in digitonin-treated cells, using wheat-germ agglutinin (WGA) which binds to the nucleoporins and inhibits the transport of importin-protein complex through the nuclear pore. The digitonin-permeabilized L1210 cells were preincubated with 50µg/ml of WGA for 20 minutes, washed and exposed to biotinylated MAL. IgG and α-lactalbumin were used as controls (Fig. 6).

Specifically, before adding biotinylated protein, cells were preincubated with 50µg/ml of wheat-germ agglutinin (WGA), 0.5mM EDTA, 0.5 mM BAPTA/AM or 10µM verapamil for 20 min at RT. The cells pretreated with WGA were then washed by centrifugation in NTB at 320 x *g* for 10 min before addition of protein.

The integrity of the nuclear membrane was tested by adding sera containing anti-nuclear antibodies to digitonin- and Triton-X100 permeabilized cells followed by incubation with

anti-human IgG antibodies (1:100) for 30 min at RT, washing by centrifugation at 320 x *g* for 10 min and visualisation as described above. Permeabilization with Triton-X 100 resulted in bright nuclear staining whereas no detectable staining was observed in the digitonin-permeabilized cells at a concentration of 40 µg/ml of digitonin. (The antibodies were kindly provided by the Clinical Immunology Laboratory, Lund).

WGA completely blocked the nuclear uptake of MAL, suggesting that transport was via the nuclear pore complex. Human IgG was not taken up in the presence or absence of WGA. Monomeric α-lactalbumin is a 14kDa protein that diffuses freely over the nuclear membrane. WGA had no effect on the uptake of α-lactalbumin into the nuclei of digitonin-treated cells. Wheat germ agglutin was also used to inhibti DNA fragmentaton in isolated nuclei and digitonin-permeabilized cells. Preincubation with 50µg/ml of WGA partially blocked the DNA fragmentation from exposure to 0.4 mg/ml of MAL (Fig. 5)

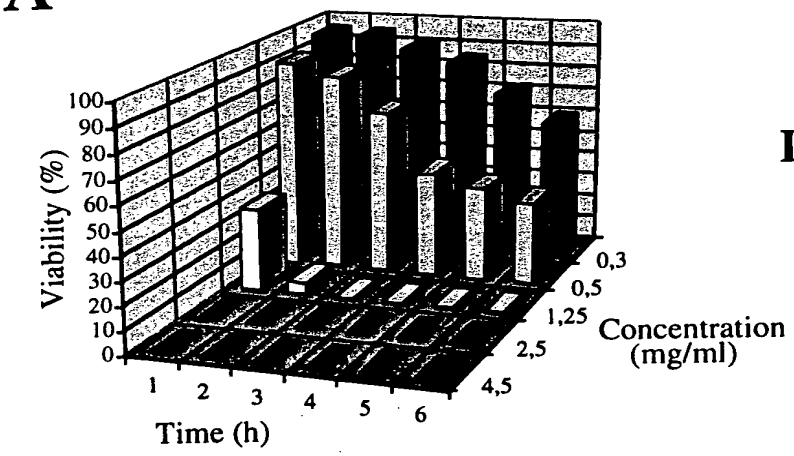
Example 7

Role of Ca^{2+} for nuclear uptake of MAL and for the induction of DNA fragmentation.

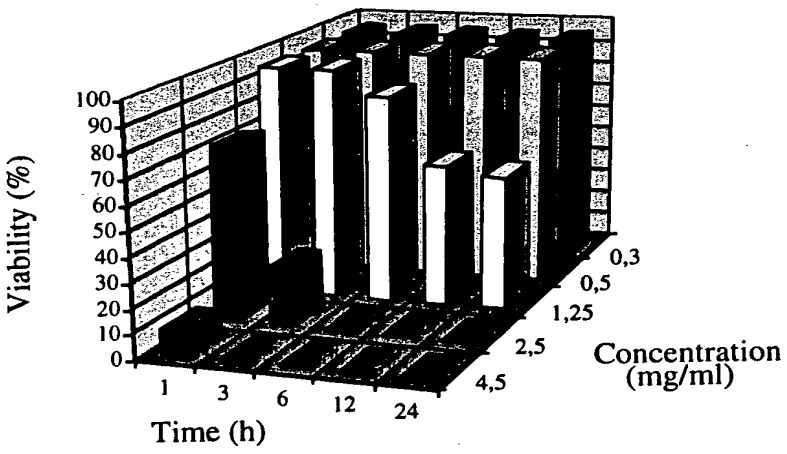
The MAL induced apoptosis was previously shown to require extracellular Ca^{2+}. This suggested that Ca^{2+} might influence the nuclear uptake mechanism and or the induction of DNA fragmentation once MAL reaches the cell nuclei. L1210, A549 and HRTEC cells were pretreated with inhibitors of Ca^{2+} uptake (verapamil and nefidipine), with extracellular Ca^{2+} - chelators (EDTA and EGTA) and with an intracellular Ca^{2+} chelator (BAPTA/AM). ^{125}I-labelled MAL was added to the cells, and the nuclear uptake was examined after 6 hours in L1210 cells and after 24 hours in A549 and HRTEC cells. The Ca^{2+} uptake inhibitors and chelators had no effect on the nuclear uptake of MAL. The MAL induced DNA fragmentation was subsequently examined in control nuclei and nuclei incubated with Ca^{2+} inhibitors. Verapamil, EDTA and BAPTA/AM completely blocked the DNA fragmentation in L1210 and A549 nuclei. These results

demonstrated that DNA fragmentation by MAL required Ca^{2+}, but that the nuclear uptake of MAL was $Ca^{2+\ I}$ independent.

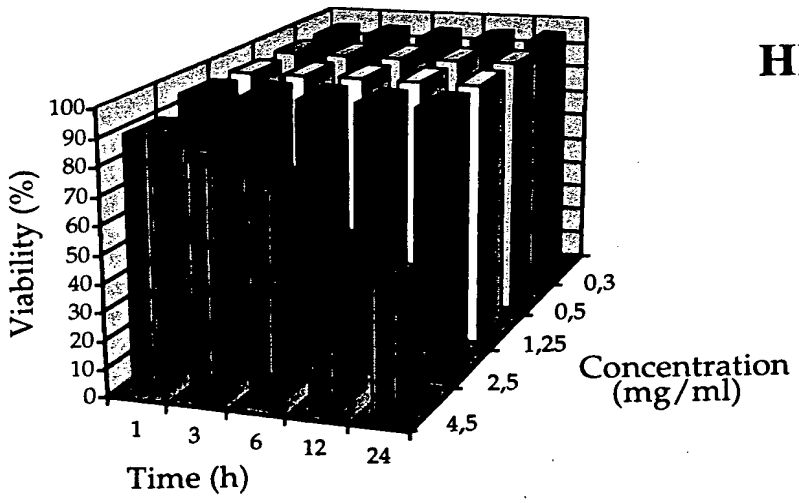
Fig. 1A



L1210



A549



HRTEC

Fig. 1B

Panel I

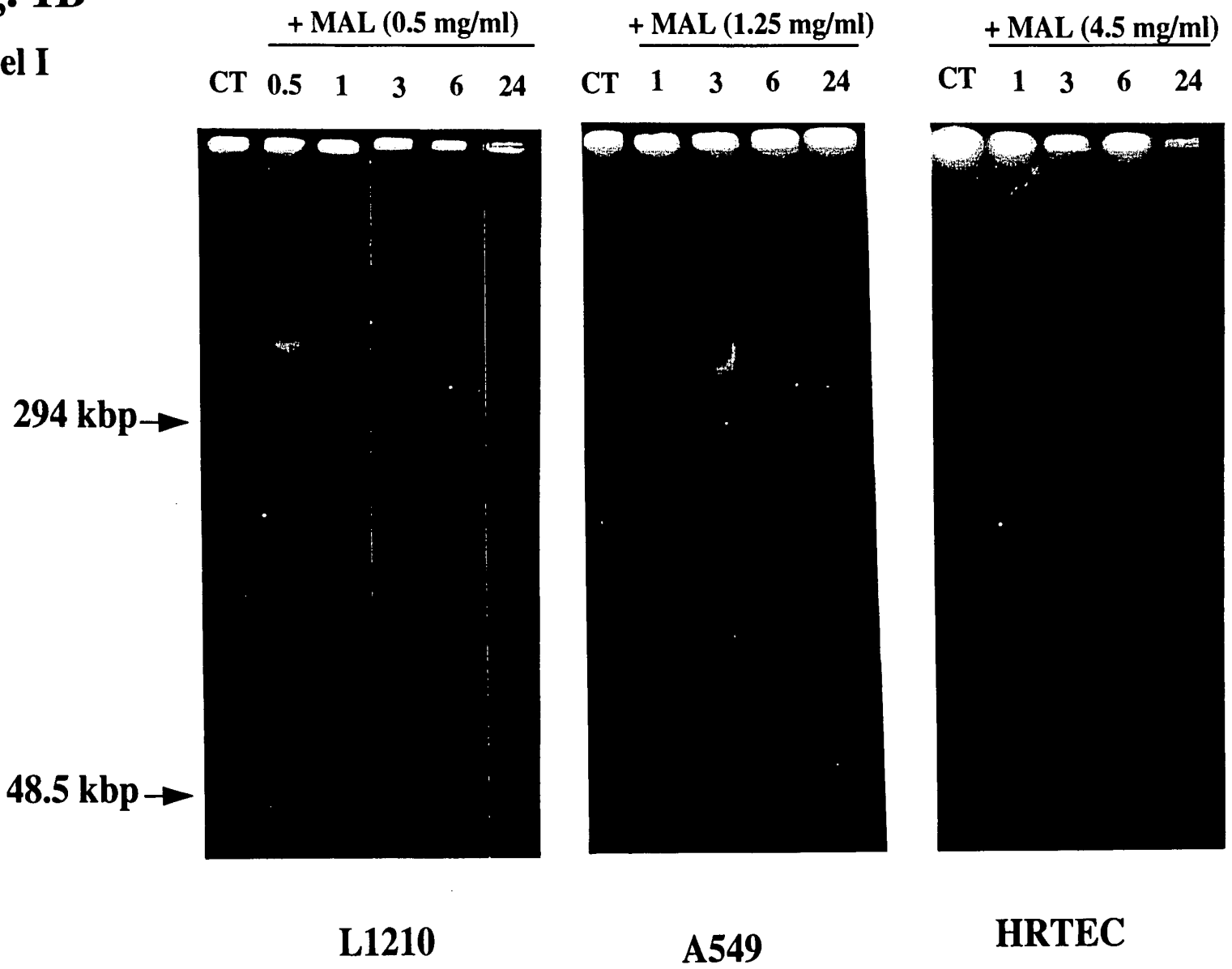
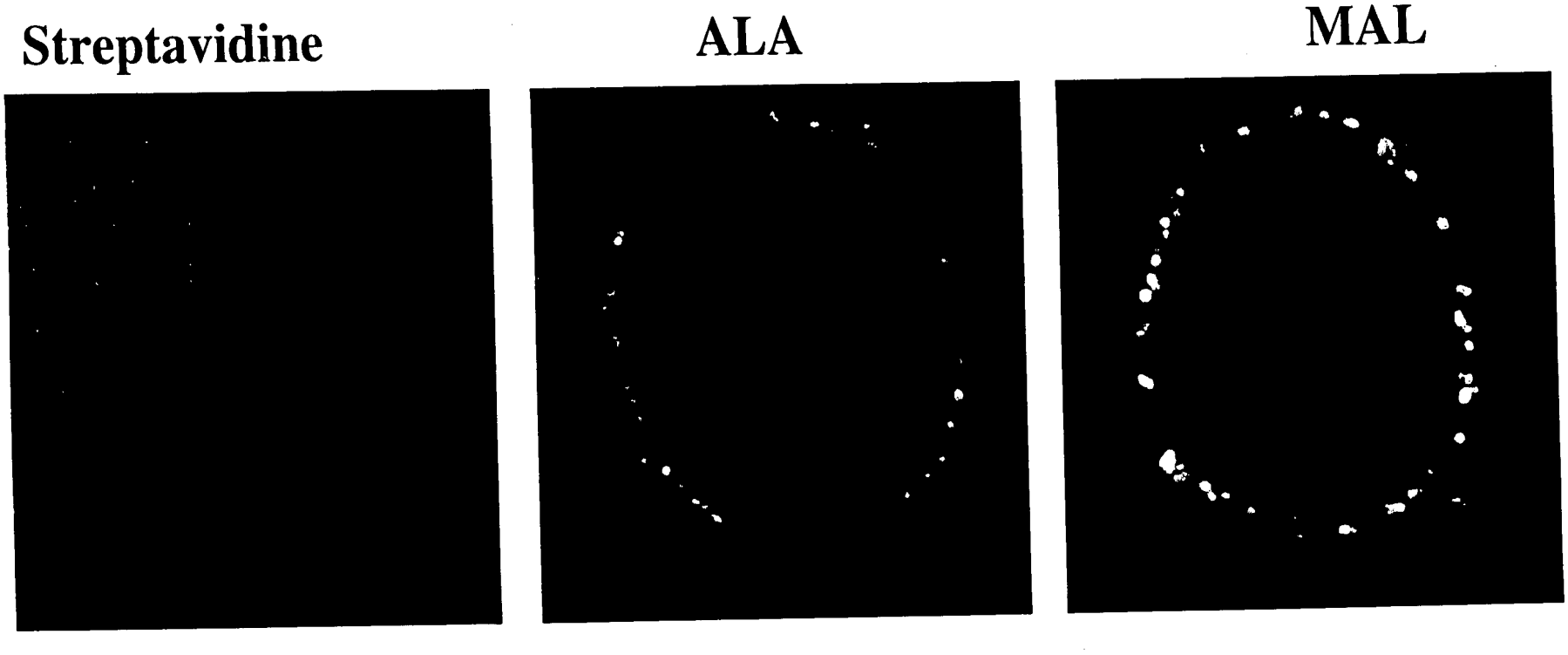


Fig. 2A



Binding detected by confocal microscopy after 30 min incubation

Fig. 2B

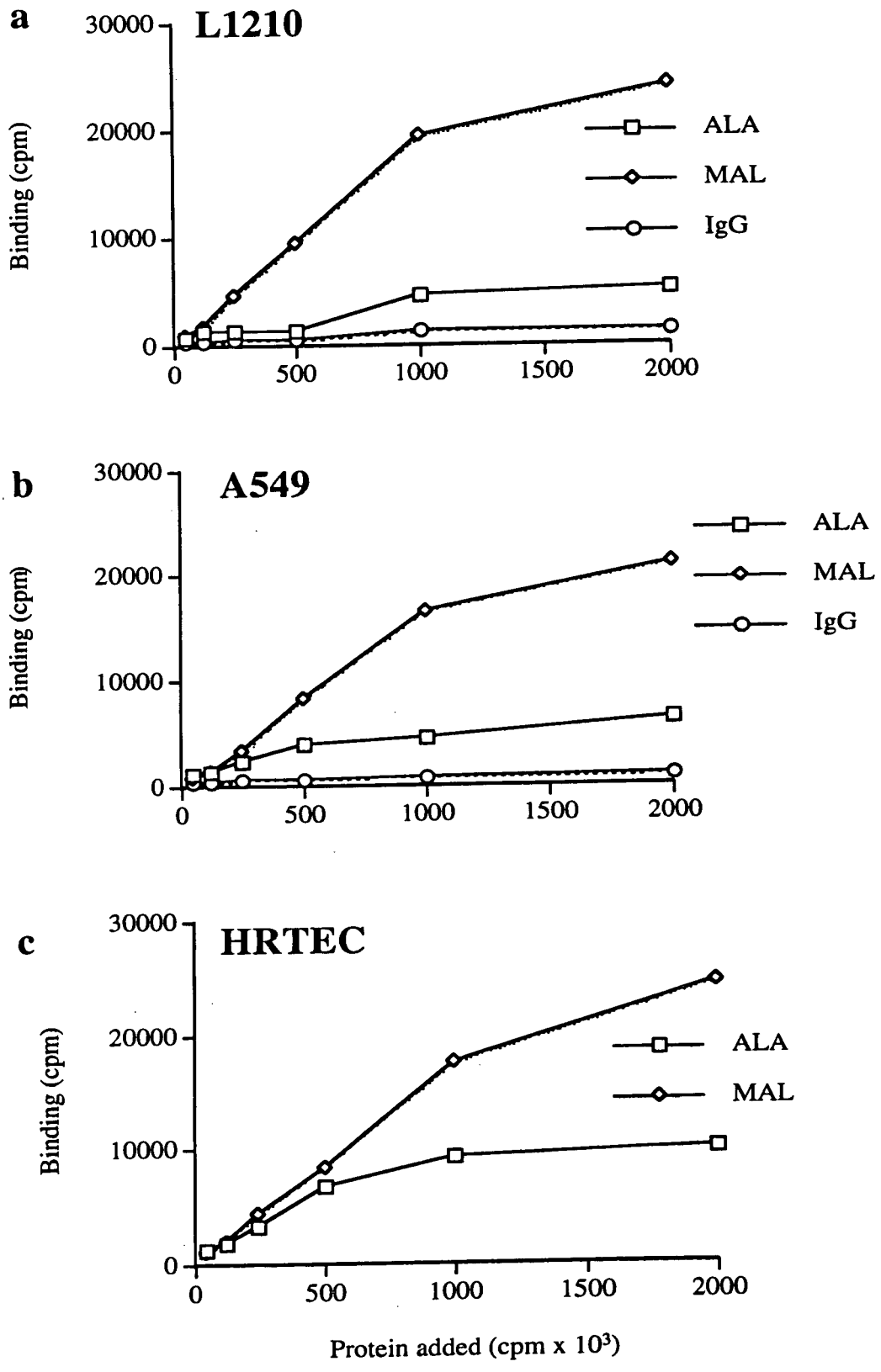

a
L1210
30000
20000
10000
0
Binding (cpm)
ALA
MAL
IgG
0
500
1000
1500
2000
b
A549
30000
20000
10000
0
Binding (cpm)
ALA
MAL
IgG
0
500
1000
1500
2000
c
HRTEC
30000
20000
10000
0
Binding (cpm)
ALA
MAL
0
500
1000
1500
2000
Protein added (cpm x 10³)

Fig. 3

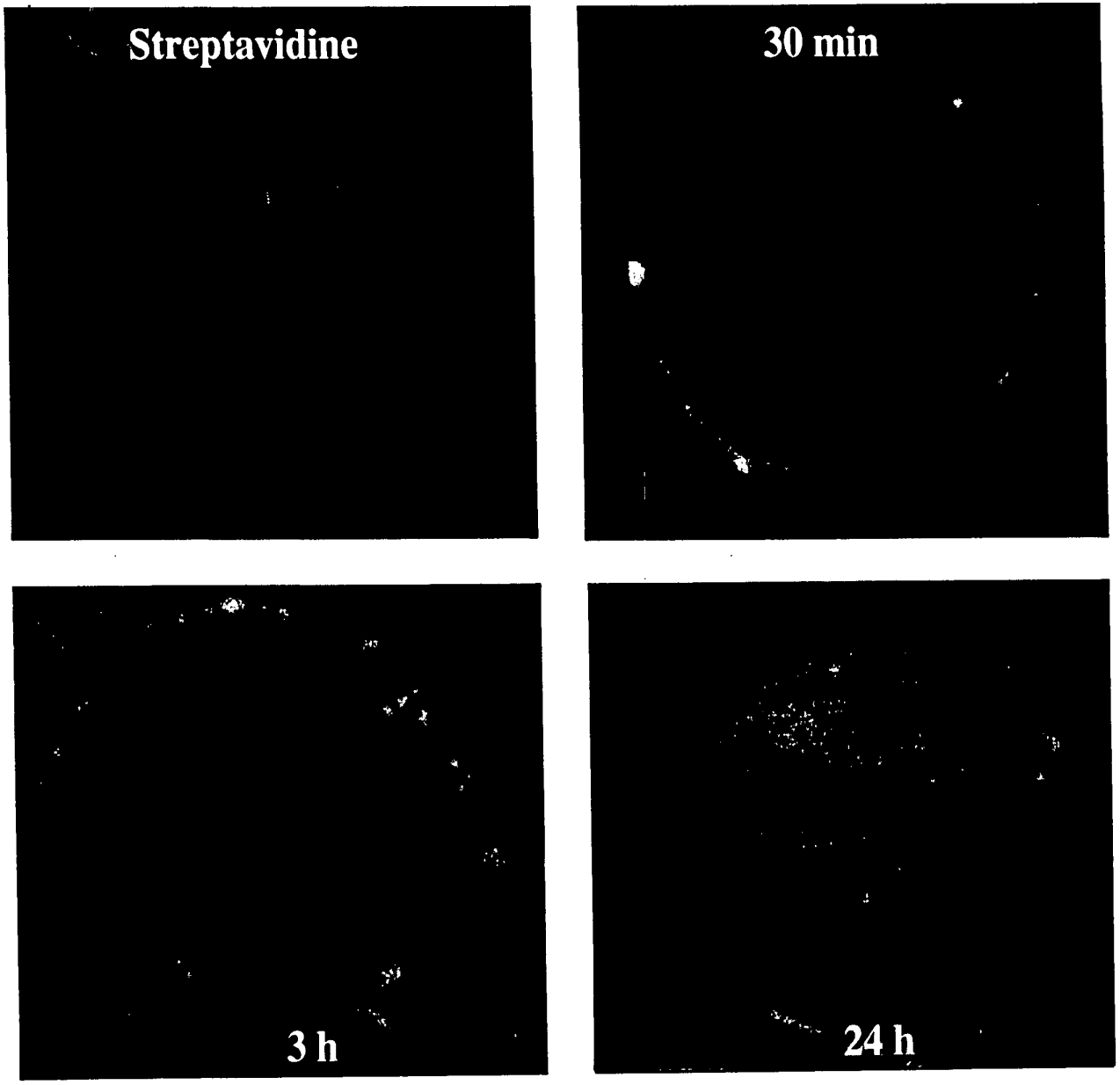


Fig. 4

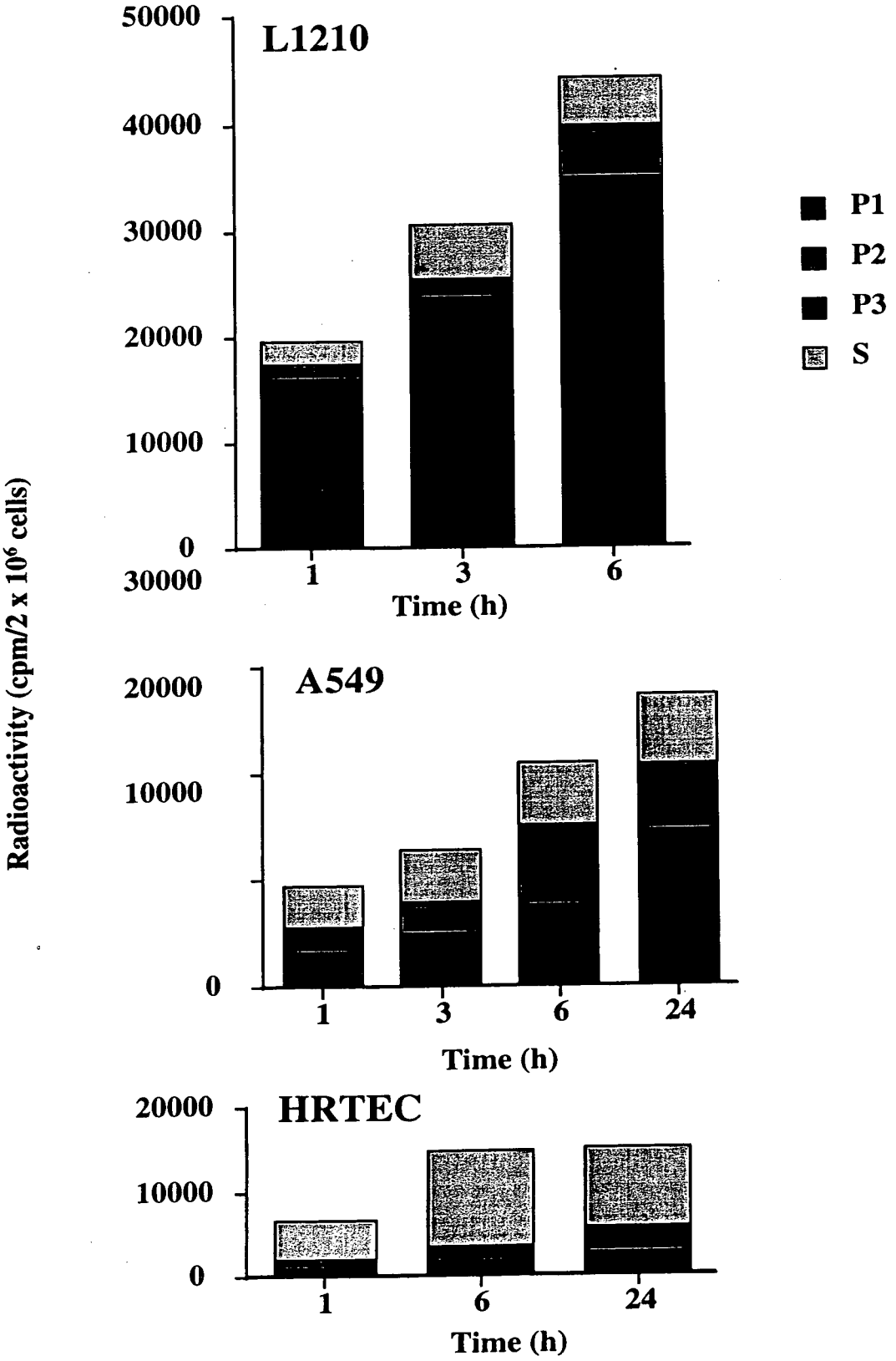

L1210
50000
40000
30000
20000
10000
0
1
3
6
Time (h)
P1
P2
P3
S
Radioactivity (cpm/2 x 10⁶ cells)
A549
20000
10000
0
1
3
6
24
Time (h)
HRTEC
20000
10000
0
1
6
24
Time (h)

Fig. 5

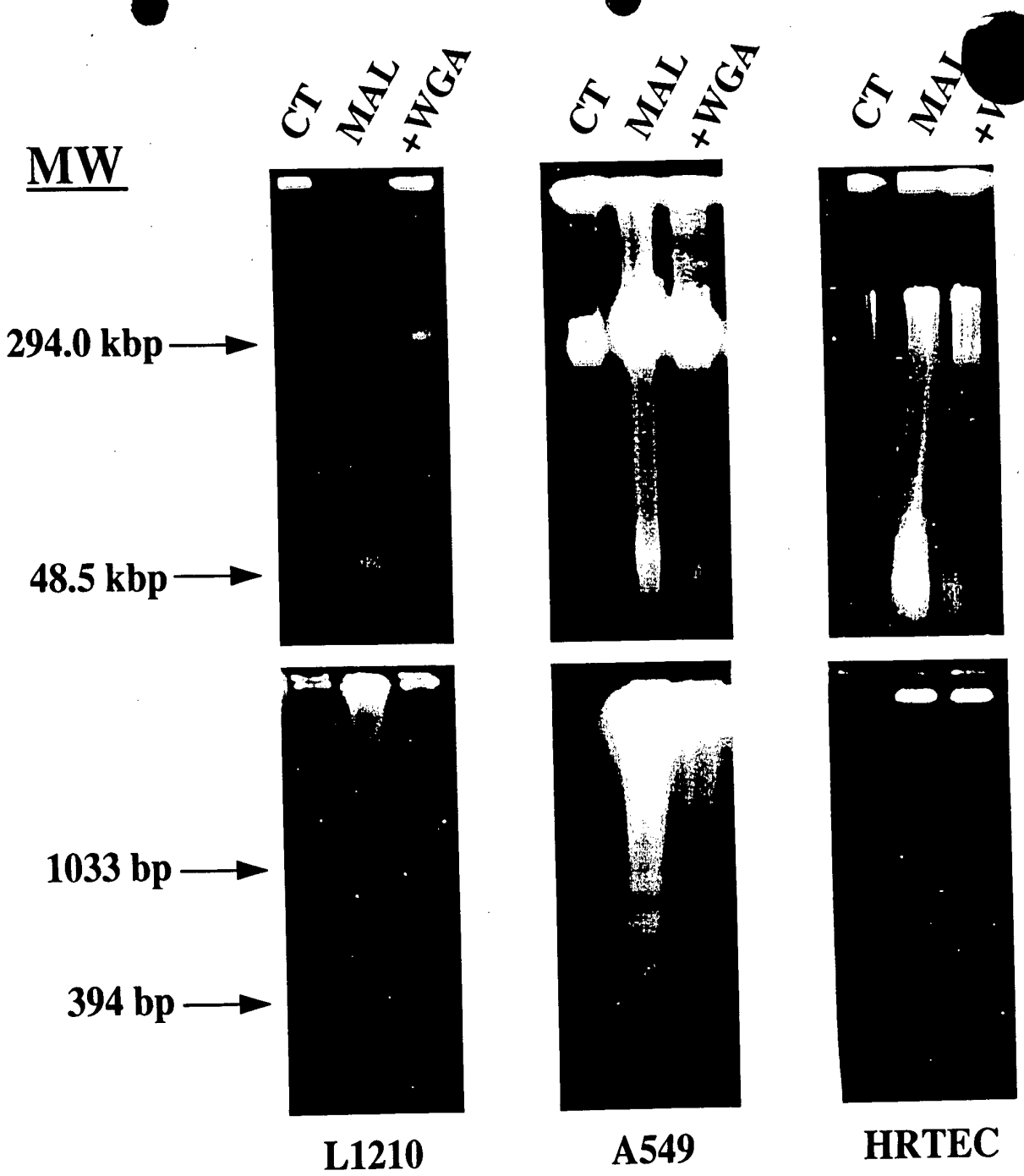

MW
CT
MAL
+WGA
CT
MAL
+WGA
CT
MAL
294.0 kbp
48.5 kbp
1033 bp
394 bp
L1210
A549
HRTEC

Fig 6